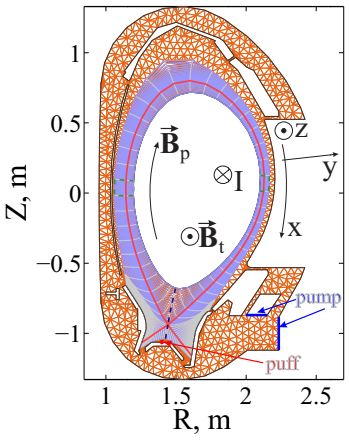
Study of detached H-modes in full tungsten ASDEX Upgrade with N seeding by SOLPS-ITER modeling

I.Yu.Senichenkov[1](e-mail I.Senichenkov@spbstu.ru), E.G.Kaveeva[1], E.A.Sytova[1], V.A.Rozhansky[1], S.P.Voskoboynikov[1], I.Yu.Veselova[1], A.S.Kukushkin[2,3], D.P.Coster[4], X.Bonnin[5] and the ASDEX-Upgrade Team.

[1] Peter the Great St.Petersburg Polytechnic University, 195251, Polytechnicheskaya ul., 29, Saint Petersburg, Russia
[2] Kurchatov Institute, Kurchatov sq. 1, 123182 Moscow, Russia,
[3] NRNU MEPhI, Kashirskoye sh. 31, 115409 Moscow, Russia
[4] Max-Planck Institut für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany
[5] ITER Organization, CS 90 046, Route de Vinon-sur-Verdon, 13067 St. Paul-lez-Durance, France

Motivation

- Our current understanding of divertor physics indicates that at least partial detachment will be a necessary condition for operation of future fusion power devices such as ITER, DEMO and beyond.
- The transition to detachment is actively studied theoretically and experimentally.
- In recent years a divertor operation regime with complete detachment was achieved in ASDEX Upgrade with tungsten walls and nitrogen seeding [1-3], and a modeling with the SOLPS5.0 transport code reproduced the main features of these experiments [4].
- In the present work the modeling similar to [4] is performed by SOLPS-ITER code [5,6] with a focus on the analysis of the effect of drifts and currents on divertor cooling and on nitrogen distribution.



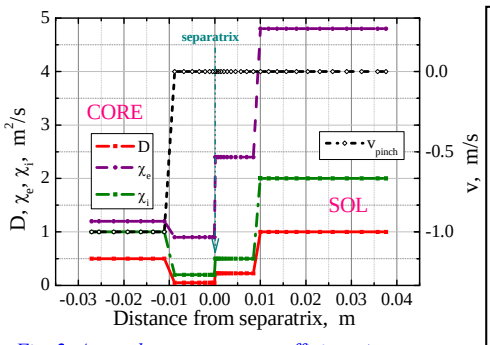


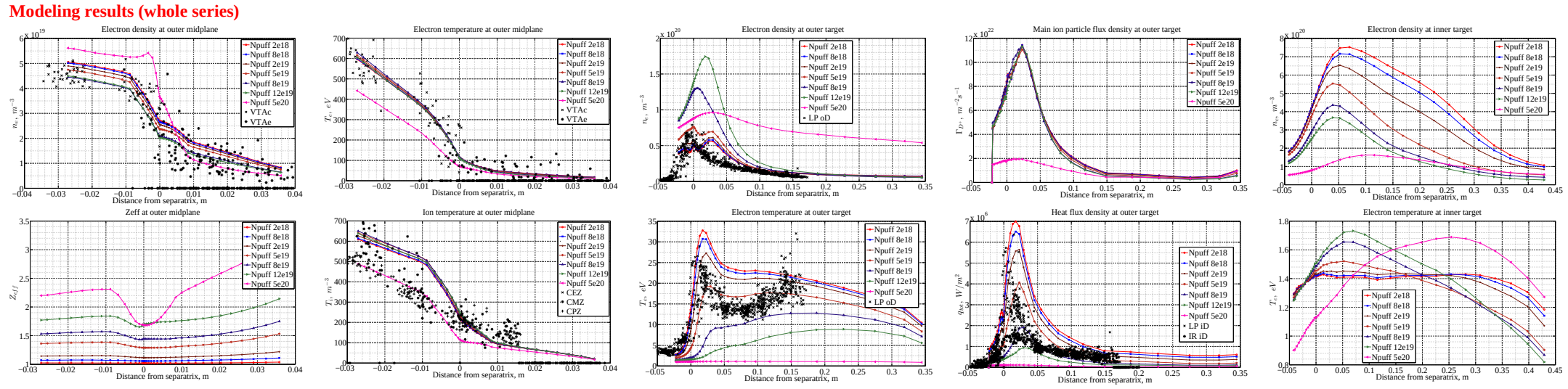
Fig. 2. Anomalous transport coefficients in equatorial midplane. In the divertor they are $[D, \chi_e, \chi_i] = [8.0, 9.6, 4.0]$ m²/s, $V_{pinch} = 0$.

← Fig.1. Computational domain.

Modeling setup

- **Drifts and currents are fully turned on.**
- Fit transport coefficients so that calculated profiles match experimental ones with reasonable accuracy, see Fig. 2. Core T_e, T_i and n_e are prescribed.
- In the succeeding calculations:
  - ✓Prescribe core D flux ($8\cdot10^{20}$ s^{-1}) due to NBI;
  - ✓Use calculated (on previous step) heat fluxes to prescribe the power in electron and ion channels ($[q_e, q_i]$ = [3.2, 1.8] MW);
  - ✓Keep anomalous transport coefficients unchanged;
  - ✓Vary only the nitrogen seeding rate from $2\cdot10^{18}$ at/s^{-1} up to $5\cdot10^{20}$ at/s^{-1}.

Modeling results (whole series)

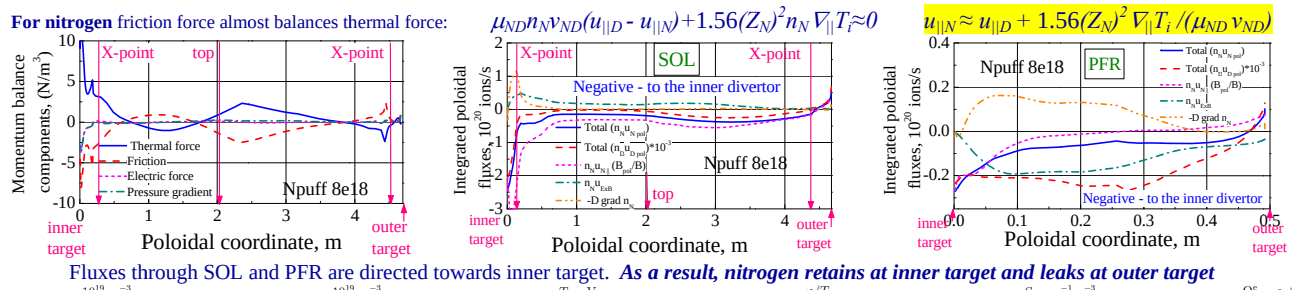


Modeling results, seeding $8\cdot10^{18}$ at/s ('high recycling at outer target')

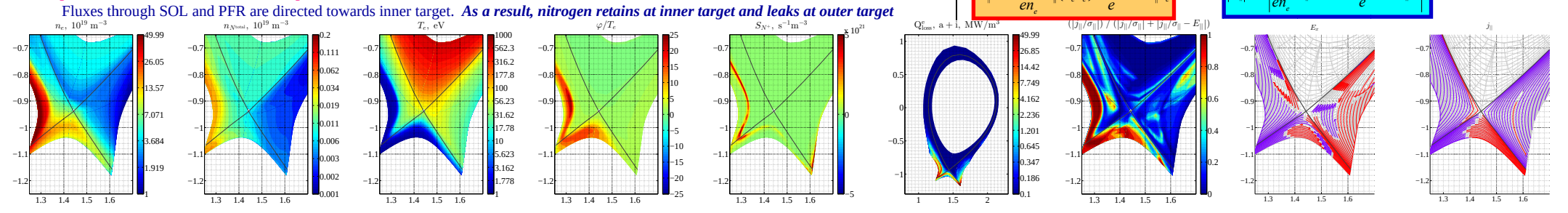
For nitrogen friction force almost balances thermal force:

$$\mu_{ND} n_N \nu_{ND}(u_{||D} - u_{||N}) + 1.56(Z_N)^2 n_N \nabla_{||} T_i \approx 0$$

$$u_{||N} \approx u_{||D} + 1.56(Z_N)^2 \nabla_{||} T_i / (\mu_{ND}\, \nu_{ND})$$



Fluxes through SOL and PFR are directed towards inner target. ***As a result, nitrogen retains at inner target and leaks at outer target***



There are 2 limiting cases in electron parallel force balance

$$\frac{j_{||}}{\sigma_{||}} = E_{||} + \frac{1}{en_e}\nabla_{||}(n_e T_e) + \frac{1}{e}0.71\nabla_{||}T_e$$

$$j_{||} = j_{PS} + j_{th}$$

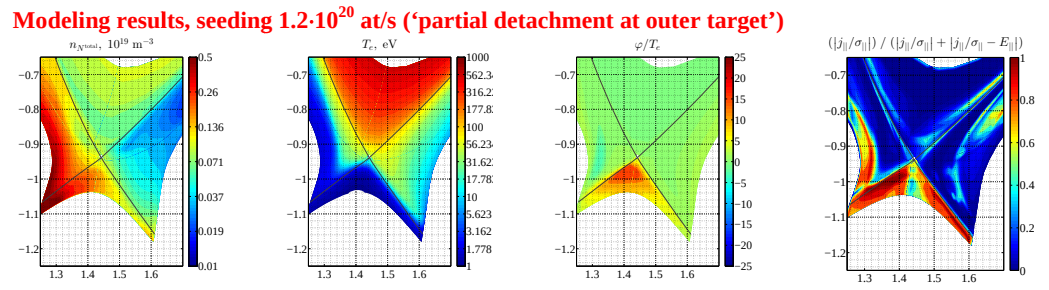
$$\left|\frac{j_{||}}{\sigma_{||}}\right| << |E_{||}|, \quad \text{high } T_e$$

$$E_{||} \approx -\frac{1}{en_e}\nabla_{||}(n_e T_e) - \frac{1}{e}0.71\nabla_{||}T_e$$

$$\frac{j_{||}}{\sigma_{||}} \approx E_{||}, \quad \text{low } T_e$$

$$|E_{||}| >> \left|\frac{1}{en_e}\nabla_{||}(n_e T_e) + \frac{1}{e}0.71\nabla_{||}T_e\right|,$$

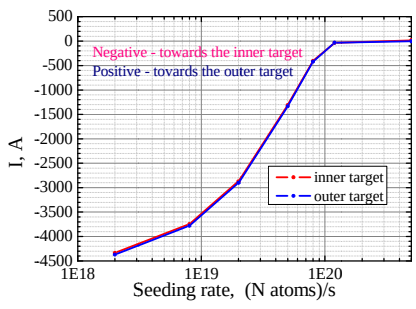
Modeling results, seeding $1.2\cdot10^{20}$ at/s ('partial detachment at outer target')



Temperature at outer target decreases, strong E-field (potential maximum near X-point) develops to drive current in PFR.

Conclusions

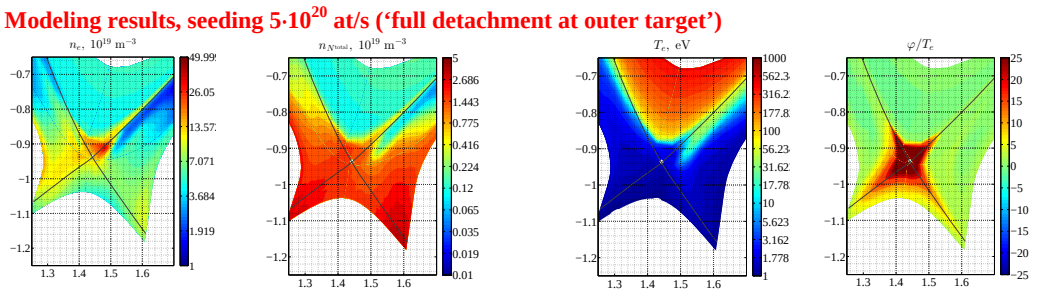
- Modeling of transition to the detachment in ASDEX Upgrade H-mode with N seeding is performed by SOLPS-ITER code with drifts and currents turned on.
- It is demonstrated that the B-parallel velocity of nitrogen is defined by the balance of thermal force and friction force.
- When the inner target is detached while outer is not, the nitrogen is concentrated near the detached inner target, and as the outer target detaches, the nitrogen accumulates near the outer target.
- As the amount of nitrogen increases and the divertor region cools a strong electric field develops to drive the current through the zones of low electric conductivity.
- The ExB drift flux becomes comparable to diffusive flux.
- Thermoelectric current reduces with the outer divertor plasma cooling, and changes its sign as the outer divertor plasma becomes colder than the inner one, similarly behaves the net current through divertor plates.

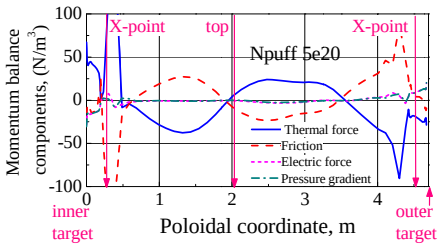


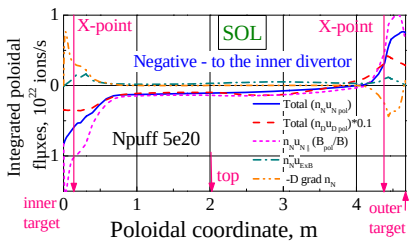
References

[1] S. Potzel *et al* Nucl. Fusion **54** (2014) 013001
[2] F. Reimold *et al* Nucl. Fusion **55** (2015) 033004
[3] A. Kallenbach *et al* Nucl. Fusion **55** (2015) 053026
[4] F. Reimold *et al* Journal of Nuclear Materials **463** (2015) 128–134
[5] S. Wiesen *et al* Journal of Nuclear Materials **463** (2015) 480–484
[6] X. Bonnin *et al* Plasma and Fusion Research **11** (2016) 1403102

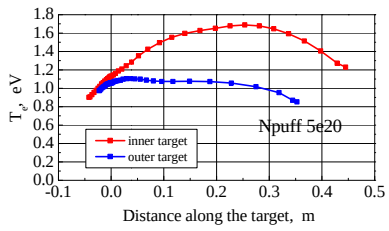
Modeling results, seeding $5\cdot10^{20}$ at/s ('full detachment at outer target')







Cooling of core plasma occurs above the X-point, so neutrals are able to penetrate there. In the strong E-field ExB drift fluxes become significant. Nitrogen retains near outer target, roll-over in n_e profile occurs. Thermoelectric current changes sign.



Acknowledgements

The work was supported by grant of Russian Ministry of Education and Science (Agreement No.14.619.21.0001, 15.08.2014, id RFMEFI61914X0001). Computations are performed in the SPbPU Supercomputer Center. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.